

## ULTRASONIC INTRACAVITY PROBE FOR 3D IMAGING

This invention relates to medical diagnostic imaging systems and, in particular, to intracavity probes for three dimensional imaging for ultrasonic diagnostic imaging systems.

Intracavity ultrasound probes have been in use for many years for imaging the body from within the body. By imaging from within the body internal organs can be imaged more directly without the need to transmit ultrasound waves through intervening tissue and body structure. For example, transesophageal probes can image the heart and abdominal organs from the esophagus or stomach and avoid the need to send and receive ultrasound through or around the ribs. The present invention relates to intracavity probes inserted in the vagina (IVT probes) or rectum (ICT probes) to image the cervix, uterus, or prostate.

In the past, IVT and ICT probes have scanned a two dimensional image region from within the body. This could be done with an array transducer or oscillating single crystal transducer which would scan a sector-shaped area of the body. By curving the elements of an array transducer completely around the distal tip region of the probe, sectors approximating  $180^\circ$  could be scanned. A typical IVT intracavity probe 10 is shown in FIGURE 1. This probe includes a shaft portion 12 of about 6.6 inches (16.7 cm) in length and one inch in diameter which is inserted into a body cavity. The ultrasound transducer is located in the distal tip 14 of the shaft. The probe is grasped and manipulated by a handle 16 during use. At the end of the handle is a strain relief 18 for a cable 20 which extend about 3-

7 feet and terminates at a connector 22 which couples the probe to an ultrasound system. A typical IVT probe may have a shaft and handle which is 12 inches in length and weigh about 48 ounces (150 grams) including the cable 20 and the connector 22.

In recent years ultrasound systems have been introduced with three dimensional (3D) imaging capability and intracavity probes have been designed to perform 3D imaging. Generally this is done by replacing the array transducer which is statically affixed in the distal tip with an array transducer which can be oscillated rapidly in the elevation direction. This oscillation will sweep the image plane being scanned through a volumetric region, acquiring multiple adjacent planar images which can be rendered into a three dimensional image. However, as was the case with earlier oscillating single crystal or annular array transducers, the oscillating array transducer of the 3D probe must be contained within a fluid through which it can oscillate and which is highly transmissive of ultrasound. Generally this fluid will be a water or oil-based solution such as a mineral oil. The fluid is preferably biocompatible so as not to injure or irritate the tissues of the patient in the event of leakage.

These mechanically oscillating 3D array probes will generally house the motor for the oscillation drive within the handle of the probe, thereby keeping it outside the body of the patient. This motor location then mandates a fluid compartment for the oscillating mechanism and transducer which extends through most of or all of the shaft and distal tip of the probe. The fluid will comprise a large portion of the weight of the probe which is located in the

shaft of the probe, causing the center of gravity of the probe to be forward of the handle and in the shaft of the probe. This imbalance makes the intracavity probe unwieldy and difficult to  
5 manipulate easily. It would be desirable to reduce the forward weight and balance of the probe so that the 3D intracavity probe is easier to manipulate during a diagnostic procedure.

In accordance with the principles of the present  
10 invention a 3D intracavity probe includes an array transducer in the distal tip which is swept to scan a volumetric region. The array transducer is swept by motor which is located in the handle of the probe. The array transducer is contained within a fluid  
15 chamber located at the distal tip of the probe and requiring less than 10 cc of fluid. As a result, the center of gravity of the shaft and handle is located in the handle and not the shaft, making the probe easier and more comfortable to hold and manipulate  
20 during use.

In accordance with further aspects of the present invention, the array transducer is mounted on an array mount made of a low mass material and displacing space within the chamber which otherwise  
25 would be filled with fluid, thereby reducing the fluid volume of the chamber. The shaft and shaft components, except for critical wear surfaces of the array drive mechanism, are also made of low mass materials such as plastics and aluminum.  
30 Accordingly, the weight of the probe is less than two-thirds of the weight of prior art 3D intracavity probes.

In the drawings:

FIGURE 1 illustrates a typical intracavity  
35 ultrasound probe of the prior art.

FIGURE 2 illustrates a side view of an intracavity probe for three dimensional imaging of the present invention.

FIGURE 3 is a side cross-sectional view of a 3D intracavity probe of the present invention.

FIGURE 4 is a perspective view of the tip assembly of a 3D intracavity probe of the present invention.

Referring now to FIGURE 2, an intracavity ultrasound probe 30 of the present invention is shown. The probe 30 includes a handle section 36 by which the user holds the handle for manipulation during use. At the rear of the handle is a strain relief 18 for the probe cable (not shown). Extending from the forward end of the handle 36 is the shaft 32 of the probe which terminates in a dome-shaped acoustic window 34 at the distal end through which ultrasound is transmitted and received during imaging. Contained within the distal end of the shaft is a transducer mount assembly 40 which is also shown in the cross-sectional view of the shaft of FIGURE 3 and in the uncovered view of FIGURE 4. A convex curved array transducer 46 is attached to a transducer cradle 48 at the distal end of the assembly 40. The transducer cradle 48 is pivotally mounted by its pivot axis 49 to be rocked back and forth in the distal end of the probe and thereby sweep an image plane through a volumetric region in front of the probe. The transducer cradle 48 is rocked by an oscillating drive shaft 50 which extends from a motor and position sensor 60 in the handle 36 to the transducer mount assembly 40. The drive shaft 50 extends through an isolation tube 52 in the shaft which serves to isolate the moving drive shaft from the electrical conductors and volume compensation

balloon 44 located in the shaft proximal the  
transducer mount assembly 40. The drive shaft 50  
rocks the cradle by means of two mating bevel gears  
54, one at the end of the drive shaft 50 and another  
5 on the transducer cradle 48. The motor alternately  
drives the drive shaft 50 in one direction of  
rotation and then the other, which alternately rocks  
the transducer cradle 48 in one direction and then  
the other, which sweeps the image plane of the  
10 transducer array 46 back and forth through the  
volumetric region in front of the distal end of the  
probe. The echo signals acquired by the transducer  
array 46 are beamformed, detected, and rendered by  
the ultrasound system to form a three dimensional  
15 image of the volumetric region scanned by the probe.

Because ultrasonic energy does not efficiently  
pass through air, the array transducer 46 is  
surrounded by a liquid which is transmissive of  
ultrasound and closely matches the acoustic impedance  
20 of the body which is approximately that of water.  
Water-based, oil-based, and synthetic polymeric  
liquids may be used. In a constructed embodiment  
silicone oil is used. In accordance with the  
principles of the present invention, only a small  
25 amount of liquid is required in the shaft 32 because  
the weight of the liquid can contribute significantly  
to the overall weight of the shaft. In some prior  
art probes the entire shaft is filled with liquid,  
adding substantial weight to the shaft and causing  
30 the center of gravity of the handle and shaft to be  
located in the shaft. Other prior art probes have  
used sizeable elastomeric bags of liquid for the  
liquid bath of the transducer array. These  
embodiments also locate the center of gravity of the  
35 probe in the shaft, which makes the probe ungainly

and difficult to maneuver easily. The liquid used in such embodiments can approach 50 cc, for instance, adding its weight to the probe shaft at the distal end.

5        In accordance with the principles of the present invention the majority of the liquid bath for the transducer array is contained within the transducer mount assembly 40. The only liquid located to the rear of the back surface 42 of the transducer mount  
10 assembly 40 (see FIGURE 2) is the small amount of the volume compensation balloon 44. In a constructed embodiment the total amount of liquid in the shaft of the probe is 6.3 cc, of which 95% is contained within the transducer mount assembly 40. Only 0.3 cc of  
15 liquid is contained within the volume compensation balloon 44, which can be kept to a small volume of liquid due to the low overall volume of liquid. In the constructed embodiment the length of the shaft 32 was 7.5 inches from the handle to the distal tip  
20 (dimension A in FIGURE 2). The transducer mount assembly 40 is contained within the distal 1.5 inches of that length (dimension B in FIGURE 2). Thus, there is only 6 cc of liquid in the forward half of the probe shaft 32, and only 6.3 cc of liquid in the  
25 entire shaft. Ninety-five percent of the liquid is in close proximity to the transducer array, located as it is in the distal 20% of the probe shaft. With so little liquid in the shaft and so little liquid in the forward half of the probe shaft, and the motor  
30 located in the handle, the center of gravity 62 of the probe handle and shaft is located in the handle, a full inch behind the handle/shaft interface (dimension C in FIGURE 2). With the center of gravity located in the handle the probe is much  
35 easier and more comfortable to manipulate during use.

In addition to the small amount of fluid needed in the forward section of the shaft, the embodiment of FIGURES 3 and 4 employ additional measures to reduce the amount of liquid and the weight of the probe shaft 32. Only critical wear surfaces within the shaft 32, such as the drive shaft 50, the gears 54, and pivot points for the transducer cradle are made of stainless steel. Selected fasteners and fittings are also made of stainless steel. Other components within the shaft are made of lighter materials with a density lighter than that of stainless steel. The transducer cradle 48 is made of three pieces of aluminum and is tapered on the sides which are the leading edges as the cradle travels through the liquid. The tapering on either side causes the cradle to move more easily through the liquid with less resistance. The space behind the transducer array and backing is not hollow but is filled so as to displace volume that would otherwise be occupied by liquid, further reducing the liquid needed in the distal end of the probe. The main body of the transducer mount assembly 40 is also made of aluminum, as is the isolation tube 52. The volume compensation balloon 44 is made of a thin plastic. The transducer array and its backing are made of material customarily used for those purposes such as piezoelectric ceramic and epoxy. This use of lightweight materials enables a constructed embodiment of the present invention including the probe shaft and handle to weigh only 250 grams, compared to the 400 gram weights of prior art probes.